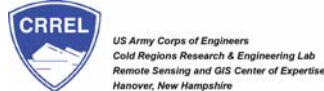


# Hubbard Glacier, Alaska: Ice Dam Formation, Stability and Outburst Floods



Daniel E. Lawson<sup>1</sup>, David C. Finnegan<sup>1</sup>, George A. Kalli<sup>2</sup> and David P. Williams<sup>2</sup>

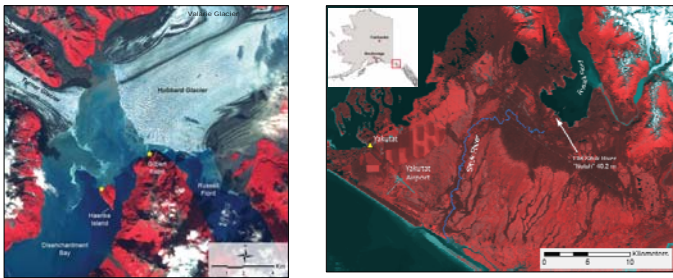
<sup>1</sup> Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH 03755

<sup>2</sup> U.S. Army Corps of Engineers, Alaska District, Anchorage, AK 99506



## INTRODUCTION

Hubbard Glacier, located approximately 50 km north of Yakutat, Alaska, is the largest temperate tidewater glacier in North America. It encompasses an area of ~3500 sq km, flowing ~120 km off the flanks of Mt. Logan (5959 m), in the Wrangell - St. Elias Mountains (Canada) to sea level where its terminus widens to ~11.5 km and discharges into Disenchantment Bay and Russell Fiord (Figure 1). In contrast to most glaciers in Southeast Alaska, Hubbard Glacier is thickening and its terminus is advancing annually at an average rate of 24 m per yr since 1895 (Trabant *et al* 2003). Its high accumulation area ratio (AAR of 0.95) suggests that Hubbard Glacier will continue to advance for decades or longer, barring any significant changes in climate altering its Equilibrium Line Altitude (ELA) (Mayo 1988; Trabant *et al* 2001; Motyka and Truffer 2007). A sustained advance of Hubbard Glacier will create an ice dam at Gilbert Point between Russell Fiord and Disenchantment Bay (Figure 1), as it did in recent times (1896, 2002), and form a 64 km long fresh water lake. In both 1986 and 2002 however, the ice dams failed and generated two of the larger outburst floods recorded in historic times. However if the ice dam remains stable and closes off Russell Fiord permanently, a lake level of elevation 40.2 m would result in drainage of lake waters through a historic channel across an end moraine at the southern end of Russell Fiord (Figure 1 right) into the Situk River. The discharge from Russell Lake could greatly exceed the capacity of the Situk River and disrupt the river's fisheries which provide much of the economic base for the community of Yakutat, as well as potentially impact the airport and other critical infrastructure.



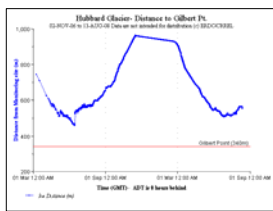
**Figure 1** - *Left* - Location of the Hubbard Glacier in Southeast Alaska. *Right* - Location map showing the town of Yakutat in relation to the Situk River and the head of Russell Fiord. 15m/pixel RGB false color composite satellite image was acquired by NASA's ASTER sensor June 12, 2003.

Understanding the dynamics of the glacier, the processes and conditions of the ice marginal environment, and the mechanics of ice dam formation and failure at Gilbert Point are critical to determining potential scenarios for the permanent closure of Russell Fiord by Hubbard Glacier and the likelihood of a stable ice dam forming that will maintain flow through the Russell moraine into the Situk River. In this poster, we briefly summarize what is known about the Hubbard Glacier system, discuss our approach to analyzing the processes and parameters determining ice dam formation at Gilbert Point, and present a draft conceptual model we are using as the basis for further investigations and data gathering to support scenario modeling of a permanent closure of Russell Fiord. Our motivation for doing so at this early stage of model development is to solicit discussion on our approach, data requirements and possible scenarios of ice dam formation, closure and failure mechanisms.

## THE HUBBARD GLACIER SYSTEM

The Hubbard Glacier is one of the few glaciers within the North Pacific region that is in a sustained advance. Observations by early Russian and European explorers indicate that the glacier had probably reached its minimum extent following a catastrophic retreat that may have ended in the early 1700's (Barclay *et al* 2001). The location of the terminus at that time is not clearly defined but may have been located near the juncture of the Valerie Glacier based on extremely limited radio echo sounding data of the elevation of the glacier's bed (Mayo 1988; Trabant *et al* 1991) (See Figure 1). Since that time, the glacier has been steadily advancing, with the first surveyed positions of the ice margin made in the late 1800's by the U.S. Coast and Geodetic Survey, followed by the well documented mapping by the International Boundary Commission in 1895. The latter survey shows the eastern half of the ice margin to have advanced significantly compared to charts and maps from the 1860 - 1870's period. The glacier has generally continued to thicken in contrast to most glaciers in the region (Arendt *et al* 2002, 2006); and advance since 1895 at rates that have increased from ~ 16 m/yr between 1895 and 1948, to an average rate of ~32m/yr through 2001 (Trabant *et al* 1991, 2003). (Figure 2). The width-averaged advance between 1992 and 2006 based on repeat satellite imagery was at a mean rate of 35 m a<sup>-1</sup> (Ritchie *et al* 2008).

Depending on location, surface ice flow rates in summer across the terminus region range from ~ 4 to 12 m d<sup>-1</sup>, the lower rates closer to the ice margin, and a seasonal variability of 1 to 2 m d<sup>-1</sup> (Krimmel and Sikonia 1986; Trabant *et al* 1991). On the eastern edge above Gilbert Point, surface flow rates are slower, averaging 5 - 6 m d<sup>-1</sup> but highly variable with the season (Motyka and Truffer 2007). Superimposed on this annual advance is a strong seasonal advance that typically begins in early March, slowing and initiating retreat in late June to late July, the glacier reaching its seasonal minimum in mid-winter (Figure 3). Across the terminus this seasonal fluctuation ranges from 150 to 200 m, varying spatially, with values as high as 300 to 500 m in the area of Gilbert Point (Finnegan *et al* 2007; Ritchie *et al* 2008). The surface elevation of the glacier is also slowly increasing at rates of about 1 to 2 m yr<sup>-1</sup> (Trabant *et al* 2003). Sparse ice thickness data along the centerline from 1986 - 1988 showed ice within 1 km of the terminus to be about 360 m thick and the bed 180 m below sea level (bsl), and at 3 km distant about 800 m thick and bed at over 400 m bsl (Trabant *et al* 1991), suggesting an overdeepened basin below the central part of the terminal lobe. Limited data up-glacier of Gilbert Point show ice is about 140 m thick and the bed ~ 85 m bsl at a km or less. Bathymetric measurements along the central ice face suggest water depths typically range from 50 to 75 meters, with a calving face ~90 meters tall; within the gap, the water depths may only be ~ 30 to 40 m at the ice face in summer..



**Figure 3**

*Left* - Terminus motion data (6-hour) acquired at Gilbert Point using a real-time laser ranging system, November 2006 (install date). *Right* - August 2008. *Above* - Oblique photo taken at water level looking into the gap between Gilbert Point and the Hubbard Glacier terminus.

Ice distance data acquired from: [www.glacierresearch.com](http://www.glacierresearch.com)

Ice dams form within the Gilbert Point area where a narrow gap currently exists and waters drain from Russell Fiord into Disenchantment Bay. Bathymetric data indicate that water depths are typically less than 30 m here (Motyka and Truffer 2007). A diurnal tidal range of up to ~6 meters drives strong tidal currents through this gap. However few quantitative measurements exist on the processes and environmental parameters affecting ice margin advance here or elsewhere along the ice margin; Motyka and Truffer (2007) measured spring and summer water temperatures in the range of ~5 to 10 degrees C, probably varying seasonally to a greater extent (~12 degrees C; Ritchie *et al* 2008). Additionally although bedrock is exposed within the face of Gilbert Point, the depth to bedrock within the gap and beneath the adjacent ice margin is not known.

The recent ice dams that formed in 1896 and 2002 did so in different ways. In 1896 the ice advance closed the channel by directly impinging on a small section of the west and central part of Gilbert Point after shoaling in the gap area had decreased calving rate, allowing for rapid advance across it (Mayo 1988). The 2002 event resulted from a spring advance and ice shove of submarine proglacial sediment against the western corner of Gilbert Point, the sediments acting as an earthen dam. In October 1986, waters rose to an elevation of 25.5 m asl before the ice dam failed, apparently due to internal and subglacial drainage that may have created a near buoyancy condition and a sudden ice collapse and outburst flood (Seitz *et al* 1986). In 2002, it reached ~15 m asl before overtopping due to intense rainfall and subsequent erosion of the moraine caused failure and a progressively increasing flood discharge.

## CONCEPTUAL APPROACH / ICE DAM MODEL

Hubbard ice dam formation is a function of multiple processes and factors that may vary temporally and spatially and involve the interaction of the glacier, marine environment, and hydrologic conditions in the Hubbard and Russell Fiord watersheds. The specific damming mechanism may differ as studies here and elsewhere reveal, and thus failure may develop through several or more mechanisms. The complexity imparted by time and space suggest the best approach is to develop potential scenarios of how ice dams may be generated at Gilbert Point, using results of previous studies, and modified by the particular dynamics, conditions and behavior of Hubbard Glacier at its terminus. The formation of an ice dam has rarely been observed and data on the mechanics of doing so are rare. Furthermore, failure mechanics are similarly difficult to measure and primarily understood through limited observations and empirical modeling (e.g. Björnsson, 1992, 2002; Walder and Costa, 1996; Anderson *et al*, 2003).

Thus our approach is to develop various scenarios for ice advance and closure and attempt to understand when an ice dam may form and become stable long enough to dam water to an elevation of 40+ m without failing. We will attempt to gather the necessary data to understand the Hubbard Glacier system and behavior on a decadal scale and how this interacts with the ice margin response to marine processes at Gilbert Point. These data will be integrated with existing empirical and quantitative methods (e.g. Clague and Mathews 1973; Walder and Costa 1996; Clarke 1982, 2007; Motyka and Truffer 2007) and the scenario models of ice dam formation, and provide a method to assess whether a permanent ice dam is likely to form and cause flooding into the Situk River.

Purpose of Investigations	Data Gathering	Information Obtained	Final Product and Benefits
Gather data necessary to develop an understanding of how Hubbard Glacier may form ice dams at Gilbert Point and understand the conditions controlling whether that ice dam is permanent or temporary.	<b>Glacier</b>  <b>Ice Margin</b>	Airborne Radar  LIDAR Imaging  Marine Geology - seismic imaging; sonar mapping  Measurements of currents, tides, bed, glacier discharge, temperature, salinity.  Ice Face Monitoring	Ice thickness, bed configuration, ice mass, water distribution, bed materials  Ice surface topography, ice flow velocity and direction;  Bathymetry, bed composition and thickness, depth and configuration of bedrock; historical flooding frequency  Magnitude of geologic forces, factors, determining dam formation, stability  Present advance and recession rates, climatic conditions
Gather existing information on Hubbard Glacier to supplement current data acquisition, and evaluate existing knowledge of ice dams and flooding as analogues for the Hubbard system.	<b>System</b>	Literature Search  Case Studies	Existing knowledge of how ice dams form, fail; analogues for flooding
Develop computer simulation model of glacier systems to integrate information.			

**Scenario model of ice dam formation;**  
  
• Will provide a method to assess whether a permanent ice dam is likely to form and cause flooding into the Situk River drainage.  
  
• Will provide time to respond to a likely flooding event

## DATA GAPS / ACQUISITION

Although there are current data collection efforts in place at Hubbard Glacier and the surrounding region, and a large body of literature related to previous studies, there are numerous gaps in data about Hubbard Glacier and its adjacent fiords essential to understanding the Hubbard system. In particular, these data are considered critical to temporal and spatial variability in ice damming processes and will provide knowledge sufficient to address the question of whether a long term closure of Russell Fiord by an ice dam can result in overflow into the Situk River drainage.

Based on a review of existing literature and previous data holdings of federal and state agencies, important data gaps include:

### Data Acquisition - Current

Within current funding constraints, we have formulated a first-order program to acquire critical data. We are currently acquiring near real-time glacier data on activity at Gilbert Point to understand the day-to-day, seasonal and annual variability at the ice margin, while providing an early warning system of potential ice dam formation (Figure-Set 4). We have also acquired repeat airborne LIDAR data over the Hubbard terminus and begun integrating this data with other geospatial data such as bathymetry (see Figure-Set 4)

### Data Acquisition - Planned

Future and continued data acquisition include:

- Aerogeophysical studies - Ice penetrating radar and LIDAR
- Marine geophysical studies - Seismic profiles and bathymetry
- Ice marginal marine investigations
- Ice face monitoring, marine parameters and climate
- Imagery acquisition and analysis
- Synthesis of existing historical records on ice dam floods
- Possibly monitoring of select watershed streams



The current timelines for conducting the field campaigns submarine geophysical investigations within the ice marginal area in August and September of 2009 when ice conditions are normally conducive to such activities. We will also conduct current, water quality and bathymetric surveys within the gap next spring and fall, repeating the bathymetric surveys annually or semi-annually in our years. In spring 2010 (possibly 2009), we plan to conduct full-scale airborne radar investigations, while repeating the bathymetric surveys through the gap.

The sequence of studies may of course be modified as we acquire new data and knowledge that may alter our prioritization, but we feel based on review of existing data and previous studies of ice dams, that this acquisition strategy will provide the critical information required to develop a robust scenario of Hubbard ice dam formation, and model the stability and failure of the particular ice dam so formed.

## Physical Model Formulation/Concluding Discussion

The basic elements of the model will include:

- Basic ice-dynamics and ice marginal-marine processes linked to ice dam formation processes
- Ice dam stability controls and failure criteria
- Quantitative formulation incorporating existing ice dam models
- Scenario models of ice dam formation for predictive purposes

